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ABSENCE OF DECOMPRESSION SYNDROME IN RECENT AND FOSSIL MAMMALIA AND REPTILIA

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Abstract

Radiologic and gross examination of a large sample of Recent and fossil mammals and reptiles revealed avascular necrosis only in turtles and mosasaurs. Absence of avascular necrosis in other families studied suggests evolutionary development of a physiologic mechanism which allows them to avoid decompression syndrome.

Introduction

Avascular necrosis results in the death of bone (Rothschild, 1982). The devitalized bone typically becomes necrotic subsequent to loss of vascular supply. If vertebrae are affected, the necrotic bone liquefies, producing a relatively linear loss of bony matrix in the downstream region of the vascular supply (Feldman et al., 1981; Resnick et al., 1981). The same phenomenon affects the proximal femoral and humeral articular surfaces, resulting in the loss of structural and therefore mechanical integrity. If these joints are then subjected to compression, a necessary component of normal joint use, subsequent fracture of surviving subchondral bone produces discrete collapse of the articular surface.

These complications of decompression are well recognized in humans and were recently described in Cretaceous mosasaurs (Rothschild and Martin, 1987) and Cretaceous through Holocene marine turtles (Rothschild, 1987). This report describes the evidence for avascular necrosis in other vertebrates.

Methods

Specimens of marine and freshwater extant and extinct reptiles and mammals were examined in the collections of The Field Museum of Natural History, Chicago (FMNH), Institut Royal des Sciences Naturelle des Belgique, Brussels, Belgium (IRSNB), The Carnegie Museum of Natural History, Pittsburgh (CM), The University of Kansas Museum of Natural History, Lawrence, Kansas (KU), The Red Mountain Museum, Birmingham, Alabama (RMM), The American Museum of Natural History, New York (AMNH), The Museum of Comparative Zoology, Cambridge (MCZ), The British Museum (Natural History), London (PR and BMNH), and The National Museum of Natural History, Washington, D.C. (USNM).

Specimens were examined for gross evidence of avascular necrosis of proximal articular surfaces in humeri and femora as implied by focal subsidence (e.g., collapse). Vertebrae were subjected to radiologic examination utilizing two approaches. Dupont MRF 33 X-ray film with Quanta III screens (Rothschild and Martin, 1987) was used with a 0.3 mm focal spot cathode ray tube (standard X-ray technique). Portable fluoroscopy equipment (Fluroscan Imaging Systems, Health Mate, Northbrook, Illinois), was also used. The image was video-recorded for subsequent analysis. Radiation exposure varied from 40 kilovolts (KV), 10 milliamps-seconds (mas) to 80 KV 150 mas, depending on the density of the vertebrae. The X-ray (radiation) exposures were chosen to assure penetration of the specimen, and to retain sufficient contrast to identify intraosseous structures. The effectiveness of X-ray screening for avascular necrosis has been well documented (Resnick et al., 1981; Rothschild, 1987; Rothschild and Martin, 1987) and thus avoids destructive analysis.

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Table 1.—*Specimens examined for evidence of avascular necrosis.*

Taxon	Specimens examined	Geologic age
Reptilia		
Anapsida (subclass)		
Mesosauria		
Mesosaurus brasilinesis	CM 36259	Permian
Diapsida		
Ichthyopterygia		
Incertae sedis	CM 876, CM 7009, CM 18744, CM 47524, CM 47525	Jurassic
Ichthyosauridae		
Ichthyosaurus quadricissus	KU 443, KU 1346	Cretaceous
Ichthyosaurus communis	CM 23822	Jurassic
Ichthyosaurus macrophthalmus	CM 356	Jurassic
Ichthyosaurus platydon	IRSNB 3190	Jurassic
Omphalosauridae		
Omphalosaurus discus	CM 878	Jurassic
Choristodera		
Champsosauridae		
Champsosaurus gigas	CM 11544	Paleocene
Sphenodonta		
Sphenodontidae		
Homeosaurus	CM 6438	Jurassic
Rynchocephalus	CM 4420	Jurassic
Sauropterygia		
Incertae sedis		
Claudiosauridae		
Claudiosaurus germaini	CM 47497, CM 47498, CM 47499, CM 47500, CM 47501, CM 47053, CM 47504, CM 47505, CM 47508	Permian
Plesiosauria		
Plesiosauridea		
Plesiosauridae		
Plesiosaurus homospondylus	IRSNB 3212	Jurassic
Plesiosaurus gulo	KU 1329	Cretaceous
Elasmosauridae		
Ogmodirus martini	KU 441	Cretaceous
Elasmosaurus sp.	CM 2791, CM 2815	Cretaceous
Incertae sedis	KU 1307, KU 1309, KU 32232, USNM 8719, PR 197, PR 1629	Cretaceous
Pliosauriodea		
Leptocleididae		
Dolichorhynchops sp.	KU 1325	Cretaceous
Polycotylidae		
Polycotylus ischiadicus	KU 434, KU 6902	Cretaceous
Polycotylus latipinnis	KU 1324	Cretaceous
Cimoliasaurus sp.	RMM 2480	Cretaceous
Lepidosauria		
Elapidae		
Acalyptophis peronii	FMNH 97030	Recent
Aipysurus edyouxii	FMNH 11571, FMNH 11572	Recent
Aipysurus foliosquama	MCZ 23492, MCZ 23493, MCZ 23494, MCA 23495, MCZ 23496	Recent

Table 1.—*Continued.*

Taxon	Specimens examined	Geologic age
Astrotia stokesii	FMNH 188904, FMNH 188909	Recent
Enhydrina schistosa	FMNH 142450	Recent
Ephalophis sp.	MCZ 29788	Recent
Ephalophis greyi	BMNH 1946.1.1.89	Recent
Ephalophis mertoni	BMNH 1946.1.1.92	Recent
Hydrelaps darwiniensis	BMNH 1946.1191, AMNH 86164, AMNH 86165, AMNH 86167, AMNH 86168, AMNH 86170	Recent
Hydrophis sp.	FMNH 16704, FMNH 16707, FMNH 16709, FMNH 16664, FMNH 16730, FMNH 16764, FMNH 16769, FMNH 199550, FMNH 199562, FMNH 199566, FMNH 199567, FMNH 199557, FMNH 199581	Recent
Hydrophis belcheri	FMNH 202839	Recent
Hydrophis brookii	FMNH 141451, FMNH 111575, FMNH 164994, FMNH 164996, FMNH 164998, FMNH 164999	Recent
Hydrophis cyanocinctus	FMNH 25173, FMNH 131258, FMNH 131259, FMNH 133078, FMNH 140161, FMNH 140162, FMNH 141142, FMNH 141163, FMNH 202852	Recent
Hydrophis elegans	AMNH 82224	Recent
Hydrophis inornatus	FMNH 202864	Recent
Hydrophis kingi	MCZ 23649	Recent
Hydrophis major	AMNH 5089	Recent
Hydrophis ornatus	FMNH 202897	Recent
Hydrophis torquatus	FMNH 165028, FMNH 165031, FMNH 165034, FMNH 165035, FMNH 165039	Recent
Kerilia jerdoni	FMNH 178771, FMNH 178774, FMNH 178775, FMNH 178776, FMNH 178776, FMNH 178777, FMNH 178784	Recent
Kolpophis annadalei	FMNH 17904	Recent
Lapemis hardwickii	FMNH 40752, FMNH 133073, FMNH 125051, FMNH 131251, FMNH 131255, FMNH 131256, FMNH 133065, FMNH 133083, FMNH 133088, FMNH 141144, FMNH 141153, FMNH 142461, FMNH 142446	Recent
Microcephalophis cantoris	MCZ 23795, MCZ 5206	Recent
Microcephalophis gracilis	MCZ 20645, MCZ 23796, MCZ 23797, FMNH 23798, FMNH 178671, FMNH 25206, FMNH 178673, FMNH 178672	Recent
Pelamis platurus	FMNH 154858, FMNH 154859, FMNH 154861, FMNH 154869, FMNH 154871, FMNH 154874, FMNH 154879, FMNH 154881, FMNH 154882, FMNH 144880	Recent
Praescutata viperina	FMNH 11567, FMNH 178591, FMNH 178592	Recent
Thalassophis anomalus	FMNH 23809, FMNH 23811, FMNH 23813, FMNH 23814	Recent

Table 1.—*Continued.*

Taxon	Specimens examined	Geologic age
Mammalia		
Cetacea		
Odontoceti		
Kentriodontidae		
Kentriodon sp.	USNM 317882	Miocene
Eurhinodelphidae		
Eurhinodelphis sp.	USNM 10480, USNM 10483, USNM 13566, USNM 23102	Miocene
Phocoenidae		
Phocoena phocoena	CM 63097, USNM 217912, CM 1709, CM 63097	Recent
Delphinidae		
Ixacanthus sp.	USNM 171104	Miocene
Delphinus sp.	CM 2851	Recent
Delphinus delphis	USNM 550211, CM 1790	Recent
Globicephala macrorhynchus	USNM 504395	Recent
Grampus griseus	USNM 550407	Recent
Lagenorhynchus acutus	USNM 504154	Recent
Sotatlia fluviatisis	CM 60938, CM 60939, CM 60940	Recent
Stenella attenuata	USNM 396032	Recent
Tursiops truncatus	USNM 11409, USNM 15727, USNM 39615	Recent
Platanistidae		
Rhabdosteus sp.	USNM 187314	Miocene
Zarhachis sp.	USNM 23002	Miocene
Iniidae		
Inia geoffrensis	CM 60936, CM 60937, CM 60934	Recent
Sirenia		
Dugongidae		
Dugong dugon	USNM 257107	Recent
Halitherium sp.	CM 24995	Miocene
Trichechidae		
Trichechus inunguis	CM 59579, CM 79986	Recent
Trichechus manatus	USNM 552360, CM 77804	Recent
Trichechus latirostris	CM 18125, CM 18126, CM 18752, CM 19411, CM 21567, CM 77798, CM 77799, CM 77800, CM 77801, CM 77802, CM 77803, CM 77804, CM 77805, CM 77806, CM 77807, CM 77808, CM 77809, CM 77810, CM 77811, CM 77812, CM 77813, CM 77814, CM 77815, CM 77816, CM 77817	
Carnivora		
Otariidae		
Callorhinus ursinus	CM 691, CM 959, CM 1484, CM 1527, CM 1562, CM 15213, CM 15218, CM 15249, CM 18738, CM 19535, CM 57378, CM 59580	Recent
Arctocephalus forsteri	USNM 550479	Recent
Zalophus californianus	USNM 252144, CM 1478, CM	Recent

Table 1.—*Continued.*

Taxon	Specimens examined	Geologic age
	1562, CM 19535, CM 21003, CM 57378, CM 59580, CM 59640	
Eumetopias jubatus	CM 958, CM 959, CM 1484, CM 1485	Recent
Odobenidae		
Odobenus rosmarus	USNM 324983	Recent
Mustelidae		
Enhydra lutris	CM 40574, CM 40575, CM 61402, CM 61403	Recent
Lutra lutra	CM 1686	Recent
Phocidae		
Leptonychotes weddelli	USNM 50507118	Recent
Mirounga angustirostris	USNM 15270	Recent
Halichoerus grypus	CM 1773	Recent
Erignathus barbatus	CM 15314	Recent
Phoca hispida	CM 15249	Recent
Phoca vitulina	CM 15213, CM 15215, CM 15218, CM 15738, CM 18739, CM 19445, USNM 15276, USNM 250713	Recent
Cystophora cristata	CM 61355	Recent
Rodentia		
Castoroidea		
Castor fiber	CM 1696	Recent
Castor canadensis	CM 25279	Recent
Monotremata		
Ornithorhynchidae		
Ornithorhynchus anatinus	CM 1788	Recent

Discussion and Results

Gross examination of humeri, femora, and vertebrae of various living and extinct reptiles and mammals (Table 1) revealed no evidence of avascular necrosis, namely, no alterations in bony architecture. Radiologic examination revealed intact vertebral bodies without evidence of abnormal radiolucency.

The bone pathology of avascular necrosis is easily recognized by the appearance of articular surface collapse or linear radiolucent vertebral resorption patterns (Feldman et al., 1981; Resnick et al., 1981; Rothschild, 1987; Rothschild and Martin, 1987). These pathologic conditions have been clearly documented in mosasaurs (Rothschild and Martin, 1987) and turtles (Rothschild, 1987) and appear to be related to repetitive diving-induced decompression syndrome.

Plesiosaurs and mosasaurs occupied similar habitats, suggesting that the lack of avascular necrosis in plesiosaurs was due to either an evolutionary compensation mechanism(s) or the fact that plesiosaurs were not deep, repetitive divers. The absence of avascular necrosis in plesiosaurs provides further evidence that its occurrence in mosasaurs is not related to radiation or bismuth poisoning (Rothschild and Martin, 1987) and further substantiates the decompression syndrome etiology of the phenomenon. Its absence in the other groups studied suggests that they either had evolved protective mechanisms (Anderson, 1966; Dennison et al., 1971; Strauss, 1970) or had diving habits quite different from those of the affected mosasaurs and turtles (Massare, 1988; Rothschild, 1987; Russell, 1967).

Review of predisposing factors and potential protective mechanisms (related to the development of decompression syndrome) should facilitate recognition of their evolution. Physiologic adaptations that reduce susceptibility to decompression syndrome are predominantly pulmonary, cardiovascular, and metabolic (Kooyman, 1989). Closer examination of the diving habits and physiology of extant reptiles and mammals should provide insights to the biology of their extinct relatives. Factors to be assessed include (Chryssanthou et al., 1974; Rothschild, 1987; Strauss, 1970; Strauss and Sampson, 1986; Tazawa and Johansen, 1987; White, 1970): 1) Nitrogen accumulation; 2) Inhalation prior to diving; 3) Type of lung (alveolar or bronchiolar and presence or absence of cartilagenous rings (preventing airway collapse); 4) Shunting of blood away from the lungs; 5) Vascular permeability; 6) Presence of cutaneous respiration/gas exchange; 7) Complement (initiation of the complement cascade) responses to micro-bubble formation; 8) Coagulation factors and heparin; 9) Blood viscosity; 10) Nitrogen excretion in the form of ammonium carbonate.

Decompression syndrome appears limited in distribution, identified to date only in mosasaurs, turtles and humans. Absence of avascular necrosis in the other reptiles and mammals analyzed in this study provides circumstantial evidence that they have developed methods of avoiding decompression syndrome. The importance of specific mechanisms may be defined in the future by comparative study of contemporary afflicted and unafflicted vertebrates. The results of such analysis would potentially provide insights to early vertebrate physiology. If one particular adaptation proved critical in contemporary animals, the geologic time of its evolution would be suggested and insight obtained to the physiology of that progenitor.

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